REMARKS

Independent claims 19 and 20 are allowed and claims 1-15 have been rejected.

Claims 1 and 14 have been amended and claim 9 has been canceled.

Applicant's independent claim 1 has been further amended to distinguish applicant's device over Brown 5,004,226. Brown '226 discloses a rectangular section rod integrally encompassed in a cylindrical sheath with a cylindrical outer diameter. The sheath has no cylindrical inner surface. The sheath prevents reorientation of the rod relative to the sheath. When the Brown '226 exercise device is used, the user orients the rod so that it is bent about the major cross section axis of the embedded rod. Brown '226 does not suggest that a rectangular section rod affording the bending resistance be placed loosely in a thermoplastic tube as defined in claim 1.

In order to more clearly define over Brown '226 and other cited art, claim 1 has been amended to define the tube as "an elongated extruded flexible thermoplastic tube containing essentially no continuous reinforcing fibers". The tube is also defined as being bendable in a semi-circle without kinking. As thus defined, it is believed clear that the rod (and not the tube) affords the desired bending resistance for the user's exercise. Independent Claim 1 was rejected as being unpatentable over Brown '226 in view of Benach. Benach uses a tubular main member 1 which is an epoxy resin matrix with continuous fiber reinforcements, both longitudinally and circumferentially. The tube 1 of Benach provides the only bending resistance, whereas applicant's rod provides primary bending resistance and applicant's tube is a housing for the rod and has minor bending resistance in comparison to the rod. Further, in paragraph **[0008]** of this application, the flexible PVC thermoplastic round tube is further identified as being 'extruded'. An extruded thermoplastic tube is constructed from only a thermoplastic resin and fillers with

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no continuous reinforcing fibers. With no continuous reinforcing fibers the extruded thermoplastic tube of similar dimensions to a Benach tube will have significantly lower 'bending stiffness' than the tube of Benach which contains continuous reinforcing fibers. And the extruded flexible thermoplastic material's properties of applicant's tube will have a significantly reduced modulus of elasticity (or relative stiffness) property as compared to the fiberglass of Brown '226 which contains continuous reinforcing fibers. Therefore, Benach teaches away from applicant's construction as claimed and the teaching of the fiberglass of Brown '226 does not suggest equivalency to the applicant's claimed thermoplastic tube member.

The cited references do not show or suggests an exercise device having a resilient rod which in cross section is wider than it is thick **and** which automatically orients itself to bend about an axis parallel to the major axis of its cross section when the flexible tube within which it is loosely housed is bent during an exercise. The automatic orientation caused by contact of the bended longitudinal edges of the rod with the interior cylindrical surface of the tube is clearly defined by amended Claim 1.

Amended claim 1 now defines the rod as being "pultruded", as described in paragraph **[0005]** of the specification. The attached Exhibit A, containing copies of the cover through page 440r-8 of a Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures of the American Concrete Institute includes a definition of "pultrusion" on page 440R-7. The pultrusion process requires the use continuous reinforcing fibers. Adding "pultruded" to the definition of the rod is believed to further distinguish over the cited art.

Claim 1 has been further amended to specifically define the interaction of the rod with the tube when the tube is bent during an exercise. The reorientation of the elongated rectangular

section rod about its major cross section axis automatically occurs "in response to forces exerted against said radiused edges of said rod by said cylindrical interior surface of said tube. Bending the rod about its major axis provides greater rod life than would be provided by an equal length round or square section rod with the same stiffness as the rectangular section rod because the radially outer circumferential tension stresses in the bent rod are less in the claimed rectangular section rod. Regardless of which direction the exercise devise is bent the rectangular section rod will orient itself so that its major cross section axis 21 is approximately parallel to the axis 41 of the oval cross section shape of the bent tube and parallel to the axis about which the exercise device is bent. The prior art does not teach a construction causing automatic orientation of an internally positioned rod; which provides a consistent bending resistance for the exercise device when the tube of the exercise device is bent in any direction.. The pressure exerted by the longitudinal edges of the rod on the interior diameter of the tube also helps the tube to flex to slightly oval cross section during bending thereby rendering the exercise device more comfortable when pressed against the body of the person exercising.

The undersigned and applicant request a personal interview with the Examiner to discuss amendments to the claims 1 and 14, to demonstrate the functional characteristic of this invention currently being marketed and to present evidence to the examiner to demonstrate significant bend characteristic differences in materials used to make bendable tubes as mentioned by the Examiner on page 2, lines 5-9 of the Office Action date February 22, 2008..

Respectfully submitted,

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21 April 2008

ACI 440R-07

Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures

Reported by ACI Committee 440

American Concrete Institute®

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First Printing
September 2007

American Concrete Institute®
Advancing concrete knowledge

Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures

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Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures

Reported by ACI Committee 440

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Several voting members of the committee contributed chapters or made other substantial contributions to the report. In addition, the committee would like to acknowledge the contribution of associate members T. Ivan Campbell and Luke A. Bisby.

Applications of fiber-reinforced polymer (FRP) composites as reinforcement for concrete structures have been growing rapidly in recent years. ACI Committee 440 has published design guidelines for internal FRP reinforcement, externally bonded FRP reinforcement for strengthening, prestressed FRP reinforcement, and test methods for FRP products. Although these guidelines exist, new products and applications continue to be developed. Thus, this report summarizes the current state of knowledge on these materials and their application to concrete and masonry structures. The purpose of this report is to act as an introduction to FRP materials in areas where ACI guides exist, and to provide information on the properties and behavior of concrete structures containing FRP in areas where guides are not currently available. If an ACI guide is available, the guide document supersedes information in this report, and the guide should always be followed for design and application purposes. ACI Committee 440 is also in the process of developing new guides and thus the current availability of guides should be checked by the reader. In addition to the material properties of the constituent materials (that is, resins and fibers) and products, current knowledge of FRP applications, such as internal reinforcement including prestressing, external strengthening of concrete and masonry structures, and structural systems, is discussed in detail. The document also addresses durability issues and the effects of extreme events, such as fire and blast. A summary of some examples of field applications is presented.

Keywords: aramid fibers; blast; bridges; buildings; carbon fibers; composite materials; corrosion; design; dowels; ductility; durability; external reinforcement; fatigue; fiber-reinforced polymer (FRP); fibers; fire; glass fiber; masonry; mechanical properties; polymer resin; prestressed concrete; seismic; stay-in-place forms; structural systems; test methods.

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ACI 440R-07 supersedes ACI 440R-96 and was adopted and published September 2007

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

The purpose of this report is to present the current state of knowledge with regard to applications of fiber-reinforced polymer (FRP) materials in concrete. This report summarizes the fundamental behavior, the most current research, design codes, and practical applications of concrete and masonry structures containing FRP. This document is intended to complement other reports (for example, standards and design guidelines) produced by ACI Committee 440, either

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by summarizing the research that supports those documents or by providing information on future developments of those documents. If an ACI guide is available, the guide document supersedes information in this report, and the guide should always be followed for design and application purposes. ACI Committee 440 is also in the process of developing new guides; thus, the current availability of guides should be checked by the reader.

FRP materials are composite materials that typically consist of strong fibers embedded in a resin matrix. The fibers provide strength and stiffness to the composite and generally carry most of the applied loads. The matrix acts to bond and protect the fibers and to provide for transfer of stress from fiber to fiber through shear stresses. The most common fibers are glass, carbon, and aramid. Matrixes are typically epoxies, polyesters, vinylesters, or phenolics.

1.2—Historical perspective of FRP composites

While the concept of composites has been in existence for several millennia (for example, bricks made from mud and straw), the incorporation of FRP composite technology into the industrial world is less than a century old. The age of plastics emerged just after 1900, with chemists and industrialists taking bold steps to have plastics (vinyl, polystyrene, and Plexiglas) mimic and outdo natural materials. Spurred on by the needs of electronics, defense, and eventually space technologies, researchers created materials with properties that seemed to defy known principles, such as bullet-stopping Kevlar. The first known FRP product was a boat hull manufactured in the mid-1930s as part of a manufacturing experiment using a fiberglass fabric and polyester resin laid in a foam mold (ACMA MDA 2006). From this modest beginning, FRP composite applications have revolutionized entire industries, including aerospace, marine, electrical, corrosion resistance, and transportation.

FRP composite materials date back to the early 1940s in the defense industry, particularly for use in aerospace and naval applications. The U.S. Air Force and Navy capitalized on FRP composites' high strength-weight ratio and inherent resistance to the corrosive effects of weather, salt air, and the sea. Soon the benefits of FRP composites, especially its corrosion resistance capabilities, were communicated to the public sector. Fiberglass pipe, for instance, was first introduced in 1948 (ACMA MDA 2006) for what has become one of its widest use areas within the corrosion market, the oil industry. FRP composites proved to be a worthy alternative to other traditional materials even in the high-pressure, large-diameter situations of chemical processing. Besides superior corrosion resistance, FRP pipe offered both durability and strength, thus eliminating the need for interior linings, exterior coatings, and cathodic protection. Since the early 1950s, FRP composites have been used extensively for equipment in the chemical processing, pulp and paper, power, waste treatment, metal refining, and other manufacturing industries (ACMA MDA 2006). Myriads of products and FRP installations help build a baseline of proven performance in the field.

The decades after the 1940s brought new, and often revolutionary, applications for FRP composites (ACMA MDA 2006). The same technology that produced the reinforced plastic hoops required for the Manhattan nuclear project in World War II spawned the development of high-performance composite materials for solid rocket motor cases and tanks in the 1960s and 1970s. In fact, fiberglass wall tanks were used on the Skylab orbiting laboratory to provide oxygen for the astronauts. In 1953, the first Chevrolet Corvette with fiberglass body panels rolled off the assembly line (ACMA MDA 2006). Now, high-performance race cars are the proving ground for technology transfer to passenger vehicles. In the 1960s, the British and U.S. Navies were simultaneously developing FRP-based minesweeper ships because FRP composites are not only superior to other materials in harsh marine environments, they are also nonmagnetic. It was also noticed at that time that one of the features of FRP is the ability of the materials to reduce the radar signature of the structure, such as a ship or an aircraft. High-performance composite materials have been demonstrated in advanced technology aircraft such as the F-117 Stealth Fighter and B-2 Bomber. Currently, FRP composites are being used for space applications and are involved in several NASA test initiatives (ACMA MDA 2006).

While the majority of the historical and durability data of FRP composite installations comes from the aerospace, marine, and corrosion-resistance industries (ACMA MDA 2006), FRP composites have been used as a construction material for several decades. FRP composite products were first demonstrated to reinforce concrete structures in the mid-1950s (ACMA MDA 2006). In the 1980s, a resurgence in interest arose when new developments were launched to apply FRP reinforcing bars in concrete that required special performance requirements such as nonmagnetic properties or in areas that were subjected to severe chemical attack.

Composites have evolved since the 1950s, starting with temporary structures and continuing with restoration of historic buildings and structural applications. Typical products developed were domes, shrouds, translucent sheet panels, and exterior building panels. A major development of FRP for civil engineering has been the application of externally bonded FRP for rehabilitation and strengthening of concrete structures.

During the late 1970s and early 1980s, many applications of composite reinforcing products were demonstrated in Europe and Asia. In 1986, the world's first highway bridge using composite reinforcing tendons was built in Germany. The first all-composite bridge deck was demonstrated in China. The first all-composite pedestrian bridge was installed in 1992 in Aberfeldy, Scotland. In the U.S., the first FRP-reinforced concrete bridge deck was built in 1996 at McKinleyville, West Virginia, followed by the first all-composite vehicular bridge deck (The No-Name Creek Bridge in 1996) in Russell, Kansas. Numerous composite pedestrian bridges have been installed in U.S. state and national parks in remote locations not accessible by heavy construction equipment, or for spanning over roadways and railways (ACMA MDA 2006).

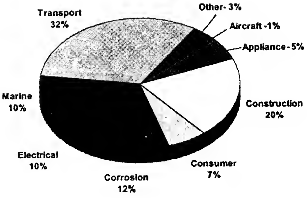

Fig. 1.1—U.S. composites shipments 2004 market share by end-use application (ACMA 2005). Total estimated volume: 1.8 billion kg (4.0 billion lb) (ACMA 2005 and PPG).

Composite fabricators and suppliers are actively developing products for the civil infrastructure, which is considered to be the largest potential market for FRP composites (ACMA MDA 2006). Concrete repair and reinforcement, bridge deck repair and new installation, composite-hybrid technology (the marriage of composites with concrete, wood, and steel), marine piling, and pier upgrade programs are just some of the areas that are currently being explored. This document describes all aspects of applications of FRP composites for concrete and masonry structures including internal reinforcement, strengthening, prestressing, and integrated stay-in-place forms.

1.2.1 *Industry statistics*—The composites industry associations and producers have traditionally tracked FRP market growth in several primary markets: aircraft/aerospace, appliance/business equipment, construction, consumer products, corrosion-resistant equipment, electrical, marine, transportation, and other applications. The American Composites Manufacturers Association (ACMA 2005) and PPG Industries reported that estimates of composites shipments in 2004 reached 1.8 billion kilograms (4.0 billion pounds). Figure 1.1 shows the distribution of FRP composites materials shipped in 2004. According to the *Composites News International* (ACMA 2005), the estimated size of the composites industry in North America is approximately $9 billion. The composites industry has shown considerable growth over the past 10 years, and is projected to increase as FRP composites are accepted in new markets.

1.2.2 *Product and benefits for construction applications*—FRP composites provide many solutions to the needs of the owner and civil engineer. FRP products for civil infrastructure/construction applications are more resistant to corrosion than reinforcing steel, thus the service life of the structure may be increased. FRP products have high strength-to-weight ratios and strength properties greater than those of steel. In repair and rehabilitation, the light weight and ease of application of the materials can result in saving in labor costs. The main drawback of the materials is their relatively high material cost.

Currently, many FRP products are available to build or repair civil engineering structures. These products have been extensively demonstrated and used around the world. Examples of FRP composite products include:

- FRP composite systems for repair, strengthening, and seismic retrofit for beams, columns, slabs, and walls;
- FRP reinforcing bars, grids, and tendons for concrete reinforcement;
- Bridge deck panels and pedestrian bridge systems;
- New structural shapes;
- Piling products and systems for marine waterfront structures;
- FRP dowel bars for durable long-term service in concrete highway pavements; and
- FRP tie connectors and FRP grid shear connectors for concrete sandwich wall construction.

Several examples of such applications are described in Chapter 13 of this report.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_f = area of FRP reinforcement, mm^2 (in.^{2})
a = depth of equivalent rectangular stress block; length of shear span, mm (in.)
b = width of carbon FRP plate, mm (in.)
c = neutral axis depth, mm (in.)
D = diameter, mm (in.)
D_i = inner diameter of tube, mm (in.)
D_o = outer diameter of tube, mm (in.)
d = distance from extreme compression fiber to centroid of tensile reinforcement, mm (in.)
d_b = bar diameter, mm (in.)
E_c = modulus of concrete core, MPa (psi)
E_{FRP} = modulus of elasticity of FRP reinforcement, MPa (psi)
E_f = equivalent orthotropic elastic modulus of tube in hoop direction, MPa (psi)
E_s = elastic modulus of steel reinforcement, MPa (psi)
f_c' = specified concrete compressive strength, MPa (psi)
f_{cc}' = compressive strength of confined concrete, MPa (psi)
f_{fu} = ultimate strength of FRP material, MPa (psi)
f_{pi} = initial prestressing stress, MPa (psi)
h = depth of reinforced concrete beam, mm (in.)
I_{cr} = cracked moment of inertia of the section of a reinforced concrete beam, mm^4 (in.^{4})
I_e = effective moment of inertia, mm^4 (in.^{4})
I_{ey} = overall effective beam moment of incrtia at yielding, mm^4 (in.^{4})
L = length of CFFT, mm (in.)
l_d = development length, mm (in.)
l_t = transfer length for prestressing tendons, mm (in.)
M_u = factored moment, kNm (lb-in.)
N = axial load, kN (lb)
R = radius of FRP tube, mm (in.)
T_g = glass transition temperature, °C (°F)
t = thickness of FRP plate, mm (in.)
V_c = nominal shear strength provided by concrete, kN (lb)
V_{exp} = experimentally obtained shear force, kN (lb)
Δ = deflection of beam subjected to load, mm (in.)
Δf_p = stress range in fatigue loading, MPa (psi)

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ε_{cc} = axial strain to calculate confinement pressure in CFFT
ε_{FRP} = strain level in FRP reinforcement
$\varepsilon_{FRP\text{-}service}$ = strain level in FRP reinforcement in service
ε_{fe} = effective strain in FRP laminate
ε_{fu} = design rupture strain of FRP
ε_s = strain of steel reinforcement
ϕ = strength-reduction factor
ϕ_u = curvature of beam at failure, 1/mm (1/in.)
ϕ_y = curvature of beam at yielding of internal steel, 1/mm (1/in.)
θ = rotation of a section of a beam, radian or degree; or direction of fibers
κ_m = coefficient to calculate effective strain in FRP laminate
μ = ductility index
ρ = reinforcement ratio
ρ_{FRP} = FRP longitudinal reinforcement ratio
ρ_{fc} = fiber composite reinforcement ratio
σ_R = confinement pressure in circular CFFT, MPa (psi)
σ_x = hoop tensile strength, MPa (psi)
σ_y = axial compressive strength, MPa (psi)
τ_m = bond strength of FRP bar, MPa (psi)
ν_c = Poisson's ratio of concrete
ν_f = longitudinal Poisson's ratio of tube

2.2—Definitions

AFRP—aramid fiber-reinforced polymer.

aging—the process of exposing materials to an environment for an interval of time.

aramid fiber—highly oriented organic fiber derived from polyamide incorporating aromatic ring structure.

balanced FRP reinforcement ratio—the reinforcement ratio in a flexural member that causes the ultimate strain of FRP bars and the ultimate compressive strain of concrete (assumed to be 0.003) to be simultaneously attained.

bar—a composite material formed into a long, slender structural shape suitable for the internal reinforcement of concrete and consisting of primarily longitudinal unidirectional fibers bound and shaped by a rigid polymer resin material. The bar may have a cross section of variable shape (commonly circular or rectangular), and may have a deformed or roughened surface to enhance bonding with concrete.

binder—chemical treatment applied to the random arrangement of glass fibers to give integrity to mats. Specific binders are used to promote chemical compatibility with the various laminating resins used.

BMC—bulk molding compound.

bond-critical applications—applications of FRP systems for strengthening structural members that rely on bond to the concrete substrate; flexural and shear strengthening of beams and slabs are examples of bond-critical applications.

braided string or rope—string or rope made by braiding continuous fibers or strands.

braiding—a process whereby two or more systems of yarns are wound together in the bias direction to form an integrated structure. Braided material differs from woven and knitted fabrics in the method of yarn introduction into the fabric and the manner by which the yarns are interlaced.

b-stage—intermediate stage in the polymerization reaction of thermosets, following which material will soften with heat and is plastic and fusible. The resin of an uncured prepreg or premix is usually in b-stage.

carbon fiber—fiber produced by pyrolysis of organic precursor fibers. Used interchangeably with graphite. Types of carbon fibers include mesophase pitch carbon and pan carbon (polyacrylonitrile).

catalyst—organic peroxide used to activate the polymerization.

CET—coefficient of thermal expansion; change in linear dimension per unit length due to change in temperature.

CFFT—concrete-filled FRP tube.

CFRP—carbon fiber-reinforced polymer (includes graphite fiber-reinforced polymer).

composite—a combination of one or more materials differing in form or composition on a macroscale. Note: The constituents retain their identities; that is, they do not dissolve or merge completely into one another, although they act together. Normally, the components can be physically identified and exhibit an interface between one another.

concrete substrate—the original concrete or any cementitious repair material used to repair or replace the original concrete; the substrate can consist entirely of original concrete, entirely of repair materials, or of a combination of original concrete and repair materials; the substrate includes the surface to which the FRP system is adhered.

contact-critical applications—applications of FRP systems that rely on continuous intimate contact between the concrete substrate and the FRP system. In general, contact-critical applications consist of FRP systems that completely wrap around the perimeter of the section. For most contact-critical applications, the FRP system is bonded to the concrete to facilitate installation, but does not rely on that bond to perform as intended. Confinement of columns for seismic retrofit is an example of a contact-critical application.

continuous fiber reinforcement—any construction of resin-bound continuous fibers used to reinforce a concrete matrix. The construction may be in the shape of continuous fiber bars, tendons, or other shapes.

continuous filament—fiber that is made by spinning or drawing into one long continuous entity.

continuous filament tow—parallel filaments coated with sizing, drawn together into single or multiple strands, and wound into a cylindrical package.

continuous filament yarn—yarn that is formed by twisting two or more continuous filaments into a single continuous strand.

coupling agent—part of a surface treatment or finish that is designed to provide a bonding link between the fiber surface and the laminating resin.

cps—centipoises, unit of viscosity. The standard unit is poise. For relatively low viscosities, the units are often referred to as centipoises (cps) or 0.01 poise. Water is the standard at 1 cps.

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crimp—waviness of a fiber, a measure of the difference between the length of the unstraightened and straightened fibers.

cross-link—a chemical bond between polymer molecules. Note: An increased number of cross-links per polymer molecule increases strength and modulus at the expense of ductility.

cure of FRP systems—the process of causing the irreversible change in the properties of a thermosetting resin by chemical reaction. Cure is typically accomplished by addition of curing (cross-linking) agents or initiators, with or without heat and pressure. Full cure is the point at which a resin reaches the specified properties. Undercure is a condition where specified properties have not been reached.

curing agent—a catalytic or reactive agent that, when added to a resin, causes polymerization. Also called hardener or initiator.

deformability factor—the ratio of energy absorption (area under the moment-curvature curve) at ultimate strength of the section to the energy absorption at service level.

denier—measure of fiber diameter, taken as the weight in grams of 9000 m of the fiber.

durability—ability to resist cracking, oxidation, chemical degradation, delamination, wear, fatigue, and/or the effects of foreign object damage for a specified period of time, under the appropriate load conditions, and under specified environmental conditions.

E-glass—a family of glass with a calcium alumina borosilicate composition and a maximum alkali content of 2.0%.

epoxy resin—resin formed by the chemical reaction of epoxide groups with amines, alcohols, phenols, and others.

extrusion—process by which a molten resin is forced through a die of a desired shape.

fabric—arrangement of fibers held together in two dimensions. A fabric may be woven, nonwoven, or stitched.

fabric, nonwoven—material formed from fibers or yarns without interlacing. This can be stitched, knit, or bonded.

fabric, woven—material constructed of interlaced yarns, fibers, or filaments.

fiber—general term for a filamentary material. Any material whose length is at least 100 times its diameter, typically 0.10 to 0.13 mm.

fiber content—the amount of fiber present in a composite. Note: This usually is expressed as a percentage volume fraction or weight fraction of the composite.

fiberglass—a composite material consisting of glass fibers in resin.

fiber-reinforced polymer (FRP)—composite material consisting of continuous fibers impregnated with a fiber-binding polymer then molded and hardened in the intended shape.

fiber volume fraction—the ratio of the volume of fibers to the volume of the composite.

fiber weight fraction—the ratio of the weight of fibers to the weight of the composite.

filament—smallest unit of a fibrous material. A fiber made by spinning or drawing into one long continuous entity.

filament winding—process for forming FRP parts by winding continuous rovings onto a rotating mandrel. The rovings may be dry or saturated with resin.

filler—a relatively inert substance added to a resin to alter its properties or to lower cost or density. Sometimes the term is used specifically to mean particulate additives.

fire retardant—chemicals that are used to reduce the tendency of a resin to burn; these can be added to the resin or coated on the surface of the FRP.

FRC—fiber-reinforced composite.

GFRP—glass fiber-reinforced polymer.

glass fiber—fiber drawn from an inorganic product of fusion that has cooled without crystallizing. Types of glass fiber include alkali-resistant (AR-glass); general purpose (E-glass); and high-strength (S-glass).

glass transition temperature—the midpoint of the temperature range over which an amphorous material (such as glass or a high polymer) changes from (or to) brittle, vitreous state to (or from) a rubbery state.

graphite fiber—fiber containing more than 99% crystalline carbon made from a precursor by oxidation.

grating—a planar FRP form. Gratings may be manufactured using molding methods or by mechanically assembling pultruded FRP elements (bars, I-shapes, or rods) together in two orthogonal directions to produce sheets.

grid—a planar FRP form in which continuous fibers are aligned in two orthogonal directions and combined with resin to produce a open mesh-like structure. Grids may be made using continuous manufacturing methods and supplied on rolls, or sheets made by molding methods and supplied in sheets.

GRP—glass-reinforced plastic.

hand lay-up—an open-mold manufacturing process in which resin is applied by hand, brush, or roller on to dry fiber reinforcements and exposed to the atmosphere for cure. This process can be done in a mold or performed on an object.

hardener—substance used to cure epoxy resins.

HFRP—hybrid FRP.

hybrid—a combination of two or more different fibers, such as carbon and glass or carbon and aramid, into a structure.

impregnation—saturation of voids and interstices of a reinforcement with a resin.

initiator—a substance, usually peroxide, that speeds up the curing of a resin.

interface—the boundary or surface between two different, physically distinguishable media. On fibers, the contact area between fibers and coating/sizing.

interlaminar shear—shearing force tending to produce a relative displacement between two laminae in a laminate along the plane of their interface.

isophthalic polyester resin—product of isophthalic acid, glycol, and maleic anhydride (Ashland Specialty Chemical 2006).

laminate—two or more layers of fibers, bound together in a resin matrix.

lay-up—the process of placing the FRP reinforcing material in position for molding.

LEED—Leadership in Energy and Environment Design—a certification program for sustainable building.

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mat—a fibrous material for reinforced polymer, consisting of randomly oriented chopped filaments, short fibers (with or without a carrier fabric), or long random filaments loosely held together with a binder.

matrix—in the case of FRPs, the materials that serve to bind the fibers together, transfer load to the fibers, and protect them against environmental attack and damage due to handling.

MF-FRP—mechanically fastened FRP.

monomer—an organic molecule of relatively low molecular weight that creates a solid polymer by reacting with itself or other compounds of low molecular weight or both.

multifilament—yarn consisting of many continuous filaments.

NDI—nondestructive inspection.

NEFMAC—new fiber composite material for advanced concrete.

NSM—near-surface-mounted.

nylon—polyamide polymer that is thermoplastic in nature.

PAN—polyacrylonitrile, a precursor fiber used to make carbon fiber.

PAN carbon fiber—carbon fiber made from polyacrylonitrile (PAN) fiber.

phenolic resin—thermoset resin produced by condensation of aromatic alcohol.

pitch—a black residue from the distillation of petroleum.

pitch carbon fiber—carbon fiber made from petroleum pitch.

plastisol—a plastisol is a liquid dispersion of polyvinyl chloride resin in a plasticizer along with materials such as stabilizers, colorants, fillers, and other additives.

ply—a single layer of fabric or mat; multiple plies, when molded together, make up the laminate.

PMC—polymer matrix composite.

polyester—one of a large group of synthetic resins, mainly produced by reaction of dibasic acids with dihydroxy alcohols; commonly prepared for application by mixing with a vinyl-group monomer and free-radical catalysts at ambient temperatures and used as binders for resin mortars and concretes, fiber laminates (mainly glass), adhesives, and the like. Commonly referred to as unsaturated polyester.

polyester resin—resin produced by the polycondensation of dihydroxy derivatives and dibasic organic acids or anhydrides yielding resins that can be compounded with styrol monomers to give highly cross-linked thermoset resins.

polymer—a high-molecular-weight organic compound, natural or synthetic, containing repeating units.

polymerization—the chemical reaction in which two or more molecules of the same substance combine to form a compound containing the same elements and in the same proportions but of higher molecular weight.

polyurethane—reaction product of an isocyanate with any of a wide variety of other compounds containing an active hydrogen group; used to formulate tough, abrasion-resistant coatings and matrixes.

postcuring, FRP—additional elevated-temperature curing that increases the level of polymer cross-linking; final properties of the laminate or polymer are enhanced.

pot life—time interval after preparation during which a liquid or plastic mixture is to be used.

precusor—the rayon, PAN, or pitch fibers from which carbon fibers are derived.

prepreg—semi-hardened fiber-matrix construction made by soaking strands or roving with resin or resin precursors.

pultrusion—process by which a molten or curable resin and continuous fibers are pulled through a die of a desired structural shape of constant cross section, usually to form a rod or tendon.

PVC—polyvinyl chloride.

reinforcement—material, ranging from short fibers through complex textile forms, that is combined with a resin to provide it with enhanced mechanical properties.

resin—polymeric material that is rigid or semi-rigid at room temperature, usually with a melting-point or glass transition temperature above room temperature.

resin content—the amount of resin in a laminate, expressed as either a percentage of total mass or total volume.

resistance factor—factor applied to a specified material property or to the resistance of a member for the limit state under considerations, which takes into account the variability of dimensions, material properties, workmanship, type of failure, and uncertainty in the prediction of resistance.

roving—a number of yarns, strands, tows, or ends of fibers collected into a parallel bundle with little or no twist.

RTM—resin transfer molding.

SCRIMP—Seemans composite reinforcement infusion molding process—a vacuum process to combine resin and reinforcement in an open mold.

SFRP—steel FRP.

shape—construction made of continuous fibers in a shape other than used to reinforce concrete monoaxially, or in the specific shape of a grid or mesh. Generally not a bar, tendon, grid, or mesh, although may be used generically to include one or more of these.

sheet, FRP—a dry, flexible ply used in wet lay-up FRP systems. Unidirectional FRP sheets consist of continuous fibers aligned in one direction and held together in-plane to create a ply of finite width and length. Fabrics are also referred to as sheets.

shelf life—the length of time packaged materials can be stored under specified conditions and remain usable.

SIP—Structurally integrated stay-in-place. Used to describe SIP form systems described in Chapter 9.

sizing—surface treatment or coating applied to filaments to improve the filament-to-resin bond and to impart processing and durability attributes.

SMC—sheet molding compound.

spray-up—method of contact molding wherein resin and chopped strands of continuous filament roving are deposited on the mold directly from a chopper gun.

spun yarn—yarn made by entangling crimped staple.

staple—short fibers of uniform length usually made by cutting continuous filaments. Staple may be crimped or uncrimped.

strand—bundle of filaments bonded with sizing.

synthetic fiber, types—polyacrylonitrile (PAN, acrylic); polyamide: nylon (aliphatic) and aramid (aromatic); polyvinyl alcohol; polyvinyl chloride (PVC); polyethylene (PE) (olefin).

textile—fabric, usually woven.

thermoplastic—polymer that is not cross-linked. Thermoplastic polymer generally can be remelted and recycled.

thermoset—resin that is formed by cross-linking polymer chains. A thermoset cannot be melted and recycled.

tow—bundle of fibers, usually a large number of spun yarns.

twisted string or rope—string or rope made by twisting continuous fibers or strands.

uncrimped—fibers with no crimp.

unsaturated polyester—product of a condensation reaction between dysfunctional acids and alcohols, one of which, generally the acid, contributes olefinic unsaturation.

URM—unreinforced masonry.

UV—ultraviolet.

vinylester resin—resin characterized by reactive unsaturation located primarily in terminal positions that can be compounded with styrol monomers to give highly cross-linked thermoset copolymers.

VARTM—vacuum resin transfer molding—a vacuum process to combine resin and reinforcement in an open mold.

volume fraction—the proportion from 0.0 to 1.0 of a component within the composite, measured on a volume basis, such as fiber-volume fraction.

weaving—a multidirectional arrangement of fibers. For example, polar weaves have reinforcement yarns in the circumferential, radial, and axial (longitudinal) directions; orthogonal weaves have reinforcement yarns arranged in the orthogonal (Cartesian) geometry, with all yarns intersecting at 90 degrees.

wet lay-up—a method of making a laminate product by applying the resin system as a liquid when the fabric or mat is put in place.

wet-out—the process of coating or impregnating roving, yarn, or fabric in which all voids between the strands and filaments are filled with resin; it is also the condition at which this state is achieved.

yarn—group of fibers held together to form a string or rope.

CHAPTER 3—CODES AND STANDARDS

This chapter provides an overview of available design documents addressing applications of FRP composite materials either as internal reinforcement or as an external repair material for concrete structures. For design guidance, the referenced design guidelines or codes should be consulted and take precedence over information in this report. With the exception of materials testing standards, the Canadian code documents (CSA S6 and S806), and the Egyptian code (Egyptian Ministry of Housing, Utilities, and Urban Development 2005), the available documents are intended to provide guidance for the use of FRP materials and do not carry the weight of design standards. In some cases, the issuing agency has chosen to term the documents Bulletins (fib 2001), Interim Guidance (IStructE 1999) or, in the case of ACI, Emerging Technology Documents (ACI 440.2R and 440.4R). Nonetheless, all are consensus documents and represent the current state of the practice. ACI removed the Emerging Technology designation from ACI 440.1R.

3.1—Materials

Most major standards-writing organizations have a number of available materials testing standards appropriate for determining a variety of FRP material properties and characteristics. Materials test standards, however, are always generic and are intended to set a standard of performance based on laboratory tests; therefore, they are not necessarily well suited to determine the in-place properties of interest to the concrete designer.

ACI Committee 440 has initiated the development of test methods specifically intended for FRP products and materials used with reinforced concrete. These ACI-developed standards are aimed at generating design values useful to the concrete practitioner. Once accepted by ACI, these test methods are submitted to ASTM Committee D30.05, "Composite Materials—Structural Test Methods" to be developed as formal ASTM standards. The first collection of ACI test methods is compiled in ACI 440.3R. ASTM D30.05 is beginning the process of revising and adopting these initial standards.

Most international standards organizations issue standards for determining basic physical properties of FRP materials. Many of these have been adapted by various industry and research interests for products with applications for concrete structures. Chapter 5 of this report discusses FRP materials testing more completely.

3.2—Internal FRP reinforcement

Fundamental design methodologies for FRP-reinforced concrete are similar to those of conventional steel-reinforced concrete. Cross-sectional equilibrium, strain compatibility, and constitutive material behavior form the basis of all code approaches to designing reinforced concrete, regardless of the reinforcing material. The nonductile and anisotropic natures of FRP reinforcing products, however, need to be addressed in design guidelines. In flexural design, for instance, the ultimate limit state may be defined either by FRP rupture or concrete crushing, provided that the strength and serviceability criteria are met. Because of the lack of ductility of such failure modes, a higher reserve of strength is required. Thus, strength-reduction factors or material-resistance factors are generally lower for FRP-reinforced concrete members than for steel-reinforced concrete members. In all cases, FRP design guidelines and codes are consistent with the applicable reinforced concrete design codes. No attempt is made to adjust load factors; thus, only strength-reduction factors or material-resistance factors are adjusted to reflect the use of FRP. Chapters 6 and 7 of this document discuss, in more detail, internally FRP-reinforced and FRP-prestressed concrete members, respectively.

ACI 440.1R uses a strength design approach for FRP-reinforced concrete members that is consistent with ACI

EXHIBIT A

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